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SHEET 14 SINNAN ROCKS

Explanatory Text of Geological Map of Sinnan Rocks, Antarctica

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1. Introduction

The Sinnan Rocks region is one of the ice-free areas in the eastern part of the Prince Olav Coast, East Antarctica. It is located at 68°54′S–68°58′S in latitude and 44°28′E–44°40′E in longitude. Geological and geomorphological survey by the Japanese Antarctic Research Expedition (JARE) in the Sinnan Rocks region was carried out for the first time by Y. YOSHIDA in 1967. Geological survey was briefly carried out in February 1974 by K. SHIRAISHI and completed by Y. HIROI and K. SHIRAISHI in February 1981. Geodetic survey was conducted by the Geographical Survey Institute in 1974 and the topographical map "Sinnan Rocks" on a scale of 1 : 25000, compiled from the air photographs taken in January 1962, was published in March 1977.

2. Geomorphology

The Sinnan Rocks are bounded by the Sinnan Glacier on the northeast and by the Nisi-Sinnan Glacier (provisional place name) on the southwest. With the maximum height of about 200 m near its inland margin the undulating surface descends gradually to the sea. A shallow and broad glacial trough cut the central part and its lower reaches are drowned to form a small embayment.

The low undulating relief of the southwestern part trends in the direction of SE-NW conformably with the trends of gneissic foliation. Glacial striation indicates the same direction of a former ice sheet flow. The south edge of the gentle surface has been eroded by the Nisi-Sinnan Glacier to form a vertical cliff in the same direction. But the cliff turns its direction to N5°W abruptly at the northeast snout of the glacier, facing to the sea. The topography shows that the flow direction of the former Nisi-Sinnan Glacier was a little but distinctly different from that of the present glacier.

The northeastern part of the Sinnan Rocks forms a complicated topography composed of small-scale rises and depressions which may be designated as "pitted surface of bedrock". To the south, the gneissic foliation perpendicular to the general trend of the former ice movement affected greatly the trend of minor relief. These features are inferred to have been shaped mainly by glacial erosion, judging from the preservation of striated surface in some places, though periglacial processes have modified the glacial relief to some extent after deglaciation. Shear moraines occur on the ice sheet close to the upper margin of the ice-free area. Constituent rocks of the moraines will be described in the next section.

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Raised beaches develop on the glaciated surface of the Kiridasi Point and the Maruhana Foreland (YOSHIDA, 1970). Beach deposits consist of gravels of pebble to boulder in size mixed with sand. The form of these raised beaches can be designated as "elevated marine-boulder pavement" (NICHOLES, 1961). Some small depressions are thought to indicate "pitted beach". The remarkable features are shingle ridges resting horizontally on headlands. They occur at the heights of about 31–32 m and 20 m on the Maruhana Foreland and of 27–29 m and 15–17 m on the Kiridasi Point (Plate 1a, b). An indistinct one is also identified at a 10 m height on the latter. The topographic characteristics suggest that sea ice pushed beach deposit to form a shingle ridge. Therefore, this ice-pushed ridge (NICHOLS, 1968) represents an approximate (though slightly higher) elevation of a former sea level. These features clearly indicate that the raised beaches have not been affected by the readvance of the ice sheet. Wave-washed bedrock with a small amount of rounded pebbles also exists below the 10 m height.

The unconsolidated deposits indicated in the geological map are shear moraines and raised beach deposits, excluding thin ground moraines and frost-riven detritus.

3. Geology and Petrography

3.1. Geology

The Sinnan Rocks region is underlain by well-layered gneisses and a granitic migmatite along with granite and pegmatite. The granitic migmatite forms concordant to discordant masses. This gneissic and migmatitic complex has been deformed twice at least, as will be discussed later. The granite and pegmatite usually occur as small discordant masses (mostly dykes). Some larger intrusions contain abundant angular blocks of country rocks. The well-layered gneisses show a wide range of bulk chemical composition (Table 1) and hence mineral assemblages, which indicate that the rocks were recrystallized under upper amphibolite-facies conditions with $P_{total} > P_{H_2O}$. The occurrence of kyanite in most of the sillimanite-biotite gneiss shows the metamorphic facies series is of kyanite-sillimanite type.

The basement rocks of the Sinnan Rocks region are classified into the following groups and sub-groups on the basis of their petrographical features.

1. Sillimanite-biotite gneiss (Gsb)
   1.1. Corundum-sillimanite-muscovite-biotite gneiss
   1.2. Staurolite-bearing sillimanite-cordierite-garnet-biotite gneiss
   1.3. Sillimanite-cordierite-biotite gneiss
   1.4. Sillimanite-garnet-biotite gneiss
2. Biotite gneiss (Gb)
   2.1. Anthophyllite-garnet-biotite gneiss
   2.2. Garnet-biotite gneiss
   2.3. Biotite gneiss
3. Biotite-hornblende gneiss (Gbh)
   3.1. Anthophyllite-garnet-biotite-hornblende gneiss
   3.2. Garnet-biotite-hornblende gneiss
   3.3. Biotite-hornblende gneiss

Table 1. Chemical compositions of rocks from the Sinnan Rocks.

No.	1	2	3	4	5	6	7
SiO_2	68.18	55.64	73.76	62.50	51.72	54.56	58.97
TiO_2	0.33	0.81	0.18	0.80	0.77	0.81	1.37
Al_2O_3	15.38	16.98	12.89	17.25	16.74	23.71	14.85
Fe_2O_3	0.88	3.02	0.36	3.41	3.48	5.11	3.75
FeO	2.23	5.07	0.61	2.06	5.14	3.58	5.98
MnO	0.01	0.19	0.06	0.15	0.26	0.50	0.18
MgO	1.49	4.52	1.62	1.70	5.65	2.86	5.33
CaO	2.77	7.09	0.78	4.45	8.85	3.21	4.81
Na_2O	5.70	3.59	4.14	4.48	3.54	3.33	3.32
K_2O	1.66	1.51	4.53	1.81	1.29	2.19	0.51
$H_2O(+)$	1.00	1.01	0.24	0.19	1.67	0.43	0.63
$H_2O(-)$	0.02	0.09	0.02	0.03	0.02	0.17	0.05
P_2O_5	0.09	0.11	0.06	0.18	0.11	0.06	0.24
Zn (ppm)	46	92	22	56	104	76	n.m.
Total	99.74	99.63	99.25	99.35	99.24	100.52	99.99

n.m.: not measured

No. 1. 81S32A Muscovite-biotite gneiss (Gb)
2. 81S32B Biotite-hornblende gneiss (Gbh)
3. 81S35B Muscovite-biotite granite (Mg)
4. 81S59 Magnetite-biotite gneiss (Gb)
5. 81S70 Biotite amphibolite (Am)
6. 81S74 Sillimanite-garnet-biotite gneiss (Gsb)
7. 81020910C Anthophyllite-garnet-hornblende-biotite gneiss (Gbh)

Analysts: Nos. 1–6 T. Hirano (Inst. Mining Geology, Akita Univ.)
No. 7 M. Tezuka and H. Onuki (Hirosaki Univ.)

4. Amphibolite (Am)
   4.1. Clinopyroxene amphibolite
   4.2. Garnet amphibolite
5. Garnet-clinopyroxene rock (Calc-silicate rock)
6. Two-mica granitic migmatite (Mg)
7. Granite and pegmatite (Gr, P)

3.2. Petrography

3.2.1. Sillimanite-biotite gneiss (Gsb)

The sillimanite-biotite gneiss forms thin layers up to 10 m in thickness traceable over a distance of several km in the region. The rock is probably derived from aluminous pelitic sediments, but its chemical composition varies from place to place within a limited area. Therefore, the rock is subdivided into the following rock types.

1) Corundum-sillimanite-muscovite-biotite gneiss: This rock occurs only in the northeastern part of the region as a thin layer intercalated with biotite gneiss and biotite-hornblende gneiss. It is well-foliated due to the preferred orientation of micas. The rock is characterized by a large amount of muscovite and also by corundum porphyroblasts up to several cm in diameter surrounded by pink K-feldspar. The constituent minerals of the rock are corundum, sillimanite, muscovite, biotite, K-feldspar, plagioclase, apatite, zircon, and opaque minerals. Trace amount of quartz is occasionally found with K-feldspar.

2) Staurolite-bearing sillimanite-cordierite-garnet-biotite gneiss: This is a fairly melanocratic medium- to coarse-grained rock of a lepidoblastic texture. It is found at several localities in the region. The constituent minerals are kyanite, sillimanite, staurolite, cordierite, garnet, biotite, plagioclase, quartz, apatite, zircon, and opaque minerals. Small amounts of secondary muscovite and chlorite are also present. Kyanite and staurolite occur as inclusions in garnet and plagioclase, suggesting that they are relict minerals formed at the earlier stage of prograde recrystallization of the rock. A similar rock has been found in the Cape Ryûgû area, the bedrock exposure next to the Sinnan Rocks region (NAKAI *et al.*, 1980).

3) Sillimanite-cordierite-biotite gneiss: This rock occurs at two localities in the region. It is a leucocratic medium- to coarse-grained rock of a granoblastic texture, and is often bluish gray in hand specimen due to the abundant fresh cordierite crystals. The constituent minerals are sillimanite, cordierite, biotite, plagioclase, quartz, apatite, zircon, and opaque minerals. Trace amounts of kyanite and garnet are occasionally found as inclusions in plagioclase, and small amounts of secondary muscovite and chlorite are also found under the microscope.

4) Sillimanite-garnet-biotite gneiss: This rock is most common among the sillimanite-biotite gneiss. It is a melanocratic medium- to coarse-grained rock of a lepidoblastic texture. The constituent minerals are sillimanite, garnet, muscovite, biotite, K-feldspar, plagioclase, quartz, apatite, zircon, and opaque minerals. Trace amount of kyanite is sometimes found as inclusions in garnet and plagioclase. The common muscovite is considered to be of retrograde origin because it usually occurs between sillimanite and K-feldspar.

3.2.2. Biotite gneiss (Gb)

The biotite gneiss is one of the most common rocks in the Sinnan Rocks region, and is probably derived from more siliceous sediments than the sillimanite-biotite gneiss. In the field, it grades into the sillimanite-biotite gneiss, biotite-hornblende gneiss, and into the two-mica granitic migmatite.

1) Anthophyllite-garnet-biotite gneiss: This rock is rare and occurs in the northwestern part of the region. It is a medium-grained rock of a lepidoblastic texture. Grayish stout crystals of anthophyllite are distinguished in hand specimen. The constituent minerals of the rock are anthophyllite, garnet, biotite, plagioclase, quartz, apatite, zircon, and opaque minerals.

2) Garnet-biotite gneiss: This rock is a fairly leucocratic fine- to medium-grained rock of a lepidoblastic texture. Reddish garnet is sporadically distributed in the rock. The constituent minerals of the rock are garnet, biotite, K-feldspar, plagioclase, quartz, apatite, allanite, zircon and opaque minerals. The amount of K-feldspar varies from specimen to specimen.

3) Biotite gneiss: This is most common among the biotite gneiss. It is a leucocratic fine- to medium-grained rock of granoblastic and/or lepidoblastic textures. Constituent minerals are biotite, K-feldspar, plagioclase, quartz, apatite, allanite, zircon, and opaque minerals. Secondary muscovite, chlorite, epidote, and prehnite are present in small amounts.

3.2.3. Biotite-hornblende gneiss (Gbh)

Biotite-hornblende gneiss is also widespread in the Sinnan Rocks region, and is probably derived from the mixture of volcanic material and sediment. In the field, it grades into biotite gneiss and amphibolite.

1) Anthophyllite-garnet-biotite-hornblende gneiss: This rock is rare and is closely associated with the anthophyllite-garnet-biotite gneiss within the garnet-biotite-hornblende gneiss. It shows a lepidoblastic texture with poikilitic green hornblende porphyroblasts. The constituent minerals are anthophyllite, cummingtonite, hornblende, garnet, biotite, plagioclase, quartz, apatite, zircon, and opaque minerals. Among the three amphiboles, anthophyllite is most abundant and cummingtonite is present only in a small amount.

2) Garnet-biotite-hornblende gneiss: This is a medium- to coarse-grained rock of a granoblastic texture. Hornblende porphyroblasts are up to 1 cm in length. The constituent minerals of the rock are garnet, biotite, hornblende, plagioclase, quartz, apatite, sphene, allanite, zircon, and opaque minerals. K-feldspar and secondary epidote, chlorite, and prehnite are sometimes present in small amounts.

3) Biotite-hornblende gneiss: This is a fairly leucocratic medium- to coarse-grained rock of a granoblastic texture. The constituent minerals are biotite, hornblende, plagioclase, quartz, apatite, zircon, and opaque minerals with or without K-feldspar. Secondary epidote, chlorite and prehnite are sometimes present in small amounts.

3.2.4. Amphibolite (Am)

Amphibolite is probably derived from basic volcanic material, because it occurs as concordant layers with other gneisses. It also occurs as lenticular blocks within the two-mica granitic migmatite.

1) Clinopyroxene amphibolite: This is a melanoclatic fine- to coarse-grained rock of massive or well-foliated textures. The constituent minerals are clinopyroxene, hornblende, plagioclase, sphene, apatite, zircon, and opaque minerals with or without scapolite, biotite and quartz. The modal amount of clinopyroxene and hornblende varies from specimen to specimen. Hornblende shows pleochroism with X'=pale yellow and Z'=bluish green to green.

2) Garnet amphibolite: This rock is less common than the clinopyroxene amphibolite. It is a melanocratic medium- to coarse-grained rock with sporadically distributed garnet porphyroblasts. The constituent minerals are garnet, hornblende, biotite, plagioclase, apatite, zircon, sphene, and opaque minerals with or without quartz. Secondary chlorite and calcite are sometimes present in small amounts.

3.2.5. Garnet-clinopyroxene rock (Calc-silicate rock)

This rock occurs as small blocks within the biotite-hornblende gneiss. It is probably derived from calcareous nodules within sediments. The constituent minerals are garnet, clinopyroxene, epidote, plagioclase, quartz, sphene, apatite, zircon, and opaque minerals. Epidote shows two modes of occurrence; as inclusions in garnet and plagioclase and as grains between garnet and plagioclase. Epidote of the latter mode of occurrence may be of retrograde origin.

3.2.6. Two-mica granitic migmatite (Mg)

The two-mica granitic migmatite occurs as concordant to discordant masses containing schlieren and lenticular blocks of amphibolite. It grades into the biotite gneiss, but is characterized by the occurrence of muscovite and magnetite porphyroblasts.

It is a fine- to medium-grained leucocratic rock of a lepidoblastic texture. It is usually gray in hand specimen, but is pinkish where it contacts granite and pegmatite. The constituent minerals of the rock are biotite, muscovite, K-feldspar, plagioclase, quartz, magnetite, apatite, allanite, and zircon. The rock is considered to be of anatectic origin during upper amphibolite-facies metamorphism.

3.2.7. Granite and pegmatite (Gr, P)

The rock occurs as small discorcant masses (mostly dykes) throughout the Sinnan Rocks region. It sometimes contains angular blocks of country gneisses. The rock is medium- to coarse-grained and pink in hand specimen. The constituent minerals are biotite, muscovite, K-feldspar, plagioclase, apatite, zircon, and opaque minerals.

3.2.8. *Constituent rocks of the moraines*

Most of the constituent rocks of the moraines are similar to the basement rock exposed in the Sinnan Rocks region. However, the following rocks are also found as moraines.

1) Hornblende-biotite-bearing mylonitic gneiss (augen gneiss): This rock has been reported from the Cape Ryûgû area, the bedrock exposure next to the present region, by NAKAI *et al.* (1980).

2) Two-pyroxene-garnet amphibolite: This is a medium-grained gneissose rock composed of orthopyroxene, clinopyroxene, garnet, biotite, hornblende, plagioclase, apatite, zircon, and opaque minerals.

3) Websterite: This is a green massive fine-grained rock composed mainly of orthopyroxene and clinopyroxene. Trace amounts of phlogopite, tremolitic amphibole, and plagioclase are also present.

4. Geologic Structure

The geologic structure of the Sinnan Rocks is complicated and the extensive migmatite makes it difficult to elucidate the original structure. The sillimanite-biotite gneiss layers can serve as useful key beds.

Foliation of the gneisses which is shown by the alternation of felsic and mafic layers is generally distinct except for the migmatitic rocks. Foliation trends northeast and gently dips southeast in the eastern part of the Sinnan Rocks, whereas it strikes predominantly northwest and moderately dips northeast and southeast in the eastern part of the region. The poles of the measured foliation are plotted on the southern hemisphere of the Schmidt's equal-area net (Fig. 1).

In a megascopic scale, an overturned antiform is found to extend from north of the Maruhana Foreland to south of the Sinnan Lake through the Namigata Terrace. The axial trace of the antiform plunges south, and is bent by the later deformation (F2; see below).

Mesoscopic tight to open folds are frequently found. The tight folds are sometimes overturned and their axial surfaces dip northeast to east (Plate 2a). Their fold axes plunge 15 to 30° southeast. On the other hand, the axial traces of the open fold generally plunge northeast to east (Plate 2b). At the Kiridasi Point, a tight fold axis which plunges 15° southeast is refolded around an axis which plunges 15° northeast. Interference patterns (RAMSEY, 1967) which are produced by these succesive foldings are

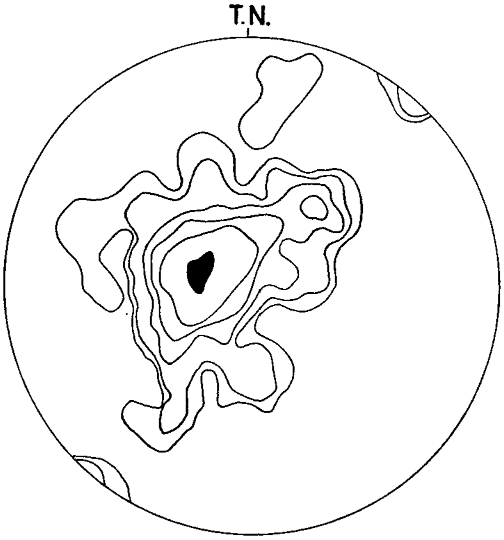

Fig. 1. Poles of mesoscopic foliation from the area surveyed.

found at some places (Plate 3c). Thus, two phases of folds are distinguished in the Sinnan Rocks; earlier tight fold (F1) and later open fold (F2).

Mineral lineation is sometimes conspicuous in the gneissic rocks. It is defined by the linear arrangements of hornblende prisms and the aggregates of biotite flakes. The mineral lineation generally dips 10 to 30° southeast and the direction corresponds to that of the F1 fold axis.

Dome structures, a few hundred meters in diameter, are revealed especially in the two-mica granitic migmatite terrain.

A set of joints which has northwest and southeast strikes and almost vertical dips is distinct all over the region.

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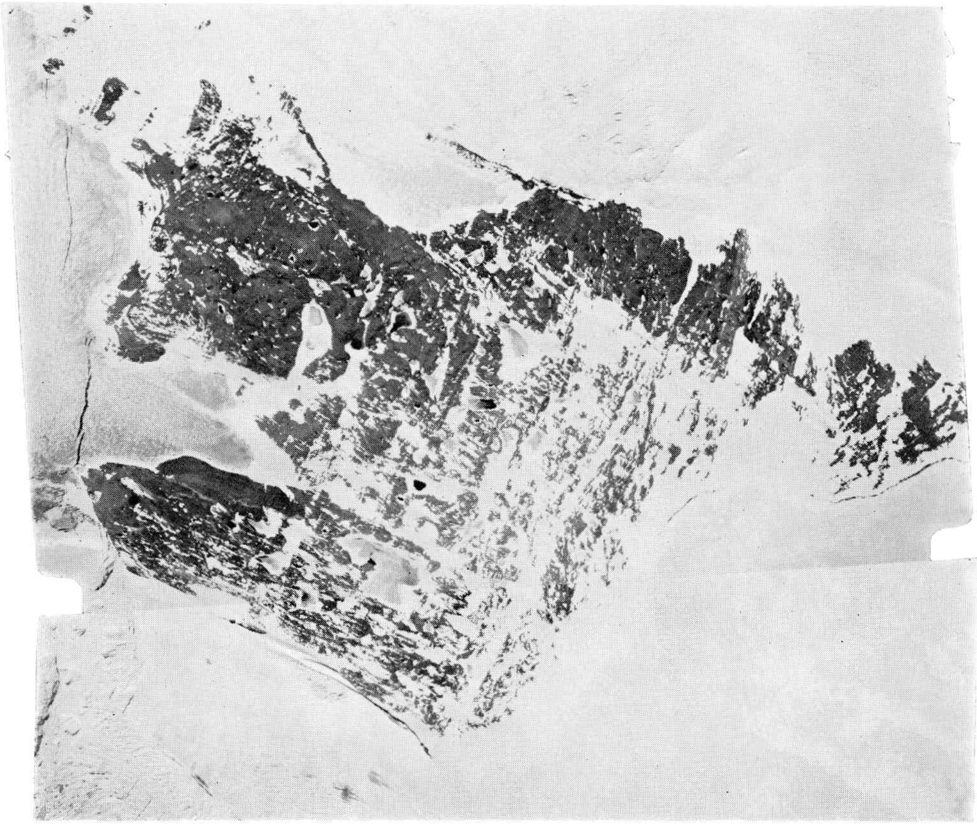
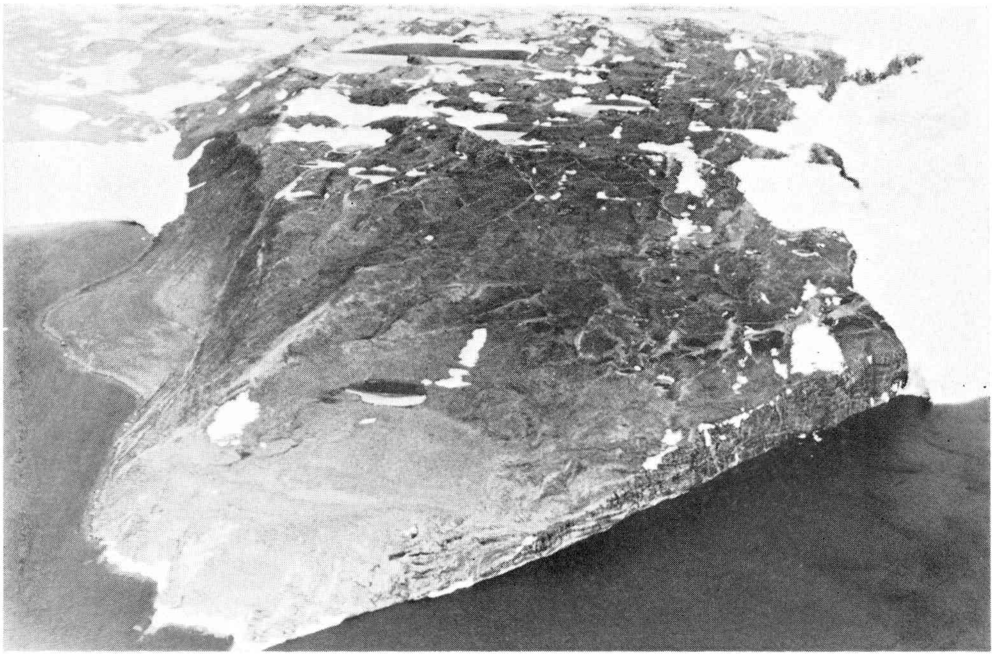
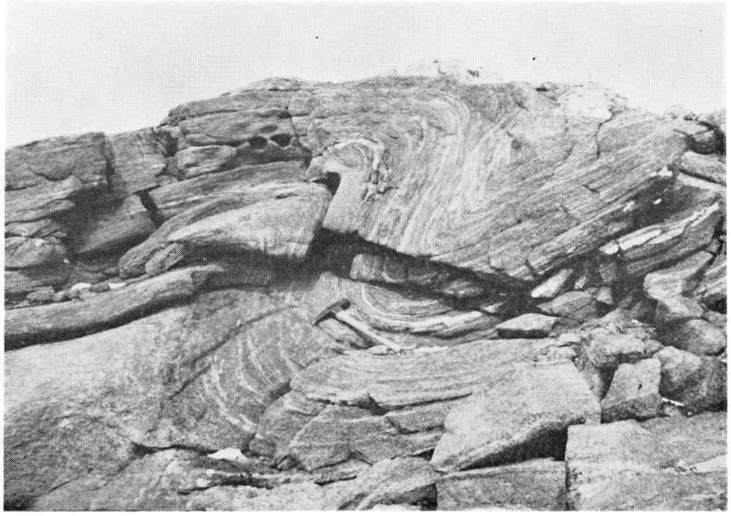


a. Aerial photograph of the Sinnan Rocks. JARE Antarctic air photographs 23AV-1, Nos. 1094 and 1095.



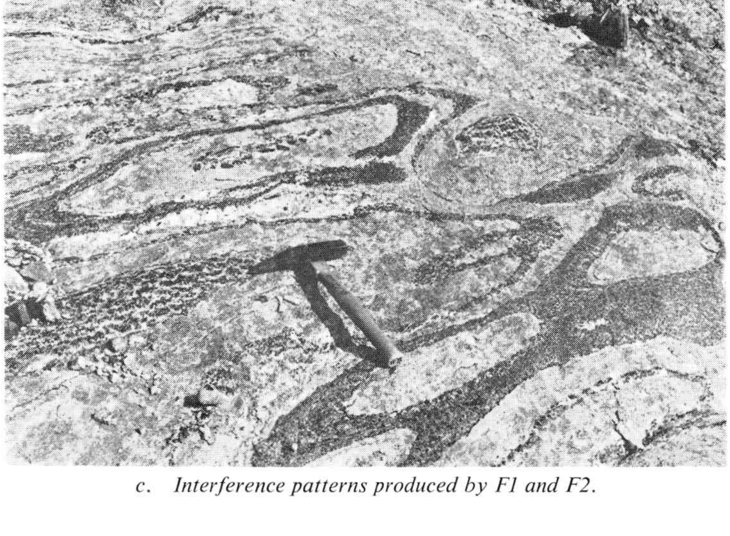
b. Oblique air photograph of the Kiridasi Point. View from the northwest.

Plate 2

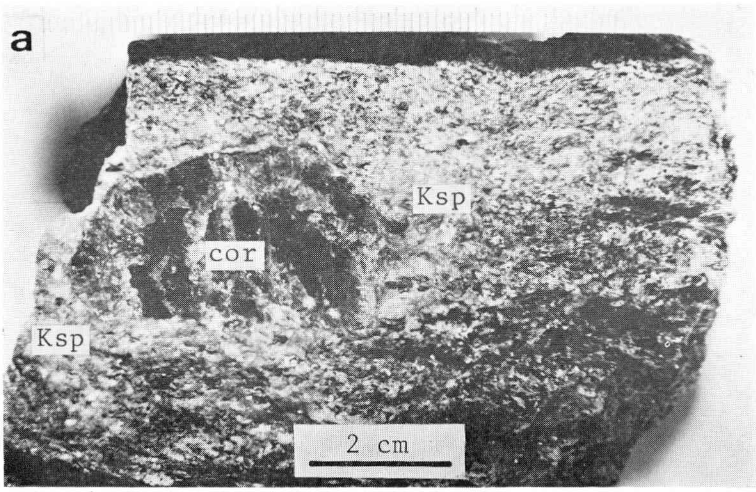


a. Outcrop showing an overturned tight fold (F1). Cross section along the E-W trend. View from the northwest.

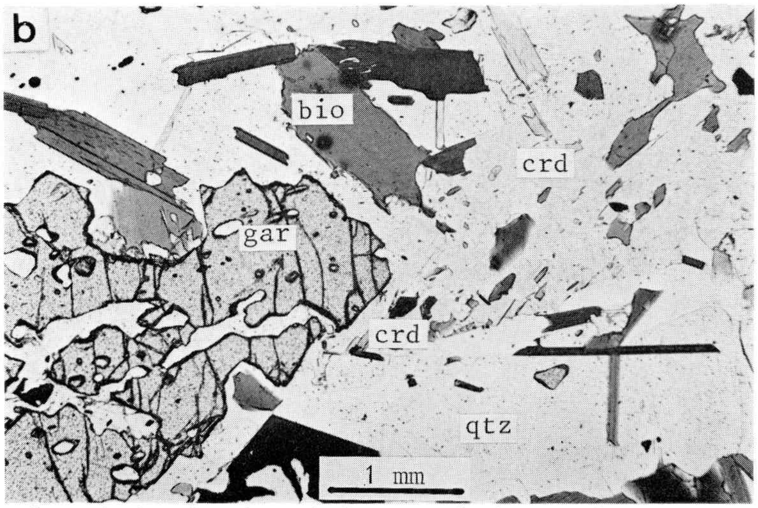
b. Outcrop showing an open fold (F2).



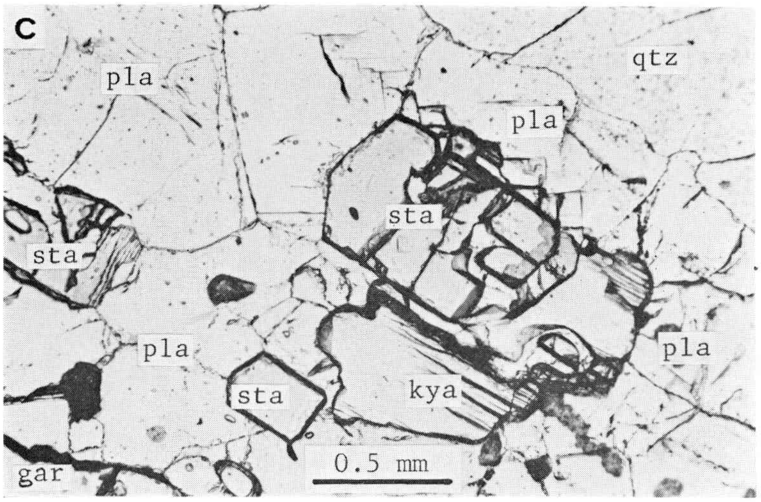
c. Interference patterns produced by F1 and F2.



a. Corundum (cor) porphyroblast surrounded by K-feldspar (ksp) in corundum-sillimanite-muscovite-biotite gneiss (sp. 81021210).

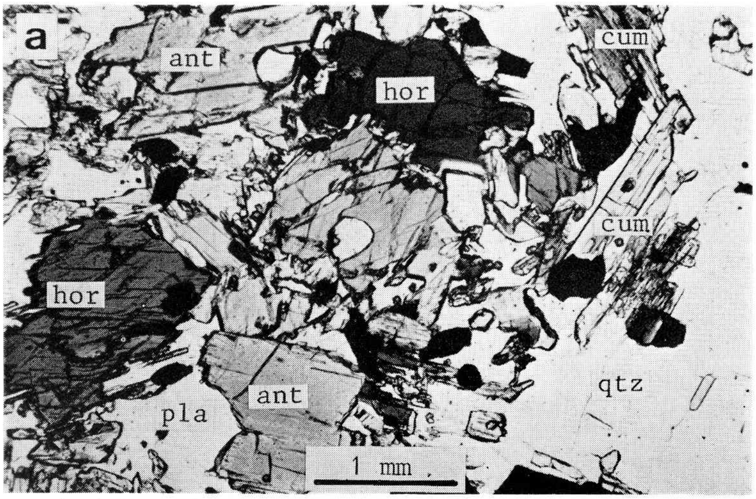


b. Garnet (gar) and cordierite (crd) in staurolite-bearing sillimanite-cordierite-garnet-biotite gneiss (sp. 81021401B). bio: biotite, qtz: quartz.

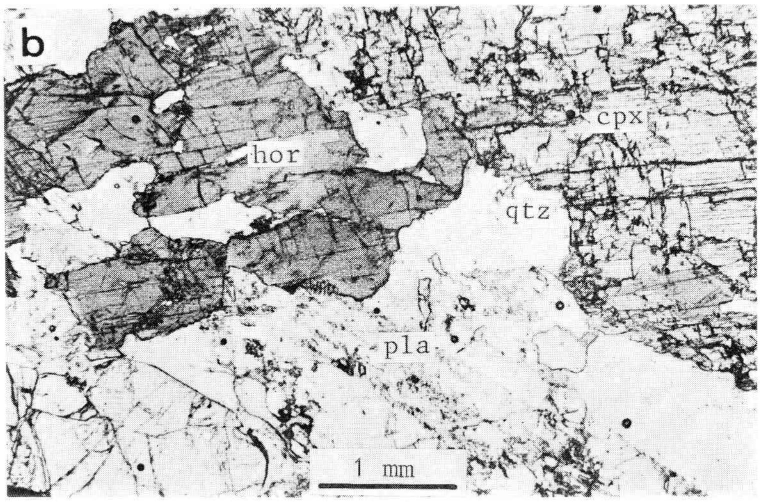


c. Staurolite (sta) and kyanite (kya) inclusions in plagioclase (pla) in staurolite-bearing sillimanite-cordierite-garnet-biotite gneiss (sp. 81021401B). Note staurolite is not in direct contact with quartz.

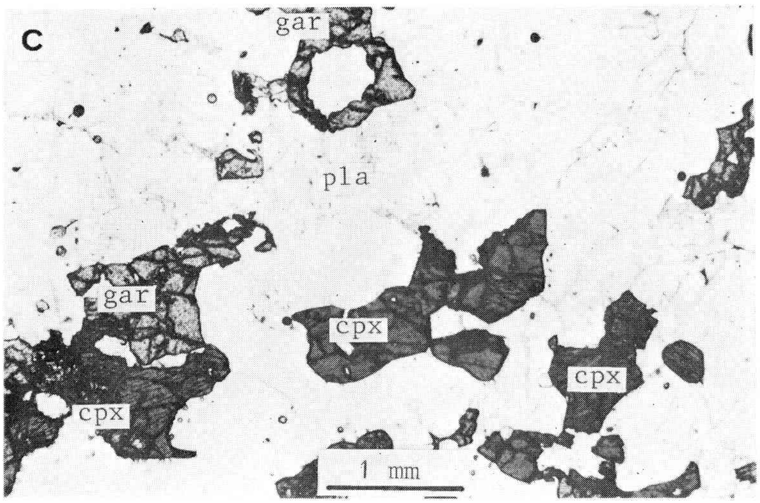
Plate 4



a. Anthophyllite (ant), cummingtonite (cum), and hornblende (hor) in anthophyllite-garnet-biotite-hornblende gneiss (sp. 81020910C). pla: plagioclase, qtz: quartz.



b. Clinopyroxene (cpx) and hornblende in clinopyroxene amphibolite (sp. 81020902B).



c. Dark green aluminous clinopyroxene and reddish garnet in garnet-clinopyroxene rock (calc-silicate gneiss, sp. 81021201B).

Antarctic Geological Map Series

Sheet 1	East Ongul Island	March 1974
Sheet 2	West Ongul Island	March 1974
Sheet 3	Teöya	March 1975
Sheet 4	Ongulkalven Island	March 1975
Sheet 5	Langhovde	March 1976
Sheet 6 & 7	Skarvsnes	March 1977
Sheet 8	Kjuka and Telen	March 1979
Sheet 9	Skallen	March 1976
Sheet 10	Padda Island	March 1977
Sheet 11	Cape Hinode	March 1978
Sheet 14	Sinnan Rocks	March 1983
Sheet 15	Cape Ryûgû	March 1980
Sheet 17	Niban Rock	March 1983
Sheet 21	Cape Omega	March 1979
Sheet 22	Oku-iwa Rock	March 1981
Sheet 27(1)	Mt. Fukushima, Northern Yamato Mountains	March 1978
Sheet 28	Central Yamato Mountains, Massif B and Massif C	March 1982
Sheet 29	Belgica Mountains	March 1981